Barker (Geo. F.)

The Forces of Nature.

AN

ADDRESS

DELIVERED

BEFORE THE CHEMICAL SOCIETY

OF

UNION COLLEGE,

JULY 22d, 1863.

BY

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ALBANY, N. Y.:

J. MUNSELL, 78 STATE STREET.

1863.

CORRESPONDENCE.

Prof. G. F. Barker:

Dear Sir—By direction of the Chemical Society of Union College, we have the honor to request for publication a copy of the very able and pleasing address delivered by you before the Society this morning.

Very truly yours,

CHAS. G. CLARK,
WM. APPLETON POTTER.

Union College, July 22d, 1863.

Messrs. Chas. G. Clark and Wm. Appleton Potter,
Committee of the Chemical Society:

Gentlemen—I thank you for the agreeable manner in which it has pleased you to request for publication a copy of the address delivered before your Society. If you deem the few thoughts so hastily thrown together to be worthy the honor you ask for them, I can only reply that, as they were prepared for the Society, they are its property, and I cheerfully place them at your disposal.

Congratulating you upon the vigorous condition of the Chemical Society,

I remain, gentlemen,
Most truly yours,

GEO. F. BARKER.

Albany, July 25, 1863.

NATURE'S FORCES.

Truth is eternal. Its principles can never be in conflict with each other. But the mistaken notion has arisen in the community that to account for natural phenomena by second causes, derogates from the character of the great First-cause. Now, the fact that Deity works by means, is proved alike in nature and in revelation; and these means are the second causes referred to. But the Divine energy is not wasted; it never provides competent second causes, and then produces the effect by direct fiat. It is only when laws fail, that Omnipotence acts directly. Whenever therefore we trace out these methods of action, we gain a clearer insight into the character of the great Father: just as we can see the mind of a fellow man by studying his writings. So that by searching out second causes, we elevate, rather than lower our ideas of God.

Premising then that it is our duty to search for natural causes to account for every known event, and that we are bound so to account for them when these causes are competent to produce them, I ask you to consider with me, in the hour allotted us, the Forces of Nature.

Whenever we speak of Force, we have a general understanding of the meaning conveyed by that term. But it is by no means easy to give an exact definition of it. We may say that Force is power; but by this we simply sub-

stitute one word for another. We may define Force to be the Divine energy pervading nature; but this, though perhaps acceptable as a theological, is not a good physical definition.

Let us therefore take a few examples among the best known forces and see in what their peculiar essence consists.

Take a rod of glass, for instance, and rub it with a piece of silk, and at once there is developed, both in the glass and in the silk, a peculiar power. By bringing light bodies in the vicinity of either the glass or the silk, they at first fly toward it, and are then repelled. Attraction and repulsion, or motion, is then a manifestation of the Force we call Electricity.

So too if we fit an iron ball accurately into a ring, and then place the ball in a fire, we shall find that when it has become hot, it will no longer pass through the ring. In common language it has expanded. But this expansion is a motion of particles from the centre toward the circumference, effected by the Force we call Heat.

We might continue this examination and include the other Forces. Light is propelled by rapid undulations of a tenuous ether. In fact, this very vibration, this motion, is the real essence of Light.

From these examples we can gather the definition of Force now generally received. Force is whatever has a tendency to produce or modify motion.[1] Either molecular, in which the ultimate atoms of the matter move, or motion of the entire mass. Considering that nothing can produce motion, but motion itself, many physicists maintain that Force is itself motion.

Moreover, Force may act in various directions and with varying intensity. It may affect the constitution of the substance upon which it acts, so altering its properties

[1] W. R. Grove, Correlation of Physical Forces, 3d ed. p. 16. Ganot, Traité de Physique, Paris, 1859, p. 13.

that it is no longer cognizable: it may give rise to new properties in matter, either temporary or permanent: or it may temporarily alter some of its previous qualities.

To illustrate; a piece of wrought iron is tough, strong, and malleable. It has a brilliant lustre, is grey in color, and fibrous in texture. Now if it be exposed for a time to the action of the weather, it is seized by a giant force, and converted into rust, which is totally unlike iron. The iron has become brittle, weak, and fragile. Its color is red, it has no lustre, and is granular in texture. The Force which has changed the metal thus, it is the chemist's province to study: he calls it Chemical Affinity. The rust he names oxide of iron and says it is no longer a simple body like iron. Would you doubt the evidence of power in this Force? There is that mighty ship to whose strength the earth and the forest have contributed. Those massive bolts which hold her sides together and enable her to defy the assaults of the waves may be silently taken apart and made weaker than a rope of sand by the action of this force, resident in the salt water. An iron rod, which a ton weight can not break even in a single section, may have every atom separated from its fellow, by a little weak acid.

But again: place this bar of iron in contact with that curious substance lodestone, and immediately it acquires a new property; that of attracting to itself other pieces of iron. If separated from the lodestone, the power is lost. If, however, the iron be previously converted into steel, a re-arrangement of its particles takes place; and if it be again presented to the lodestone, the same phenomena appear but with the difference that they are now permanent. Here a peculiar force, which we term magnetism, has imparted new properties to the metal: in the one case temporary, in the other permanent, without affecting any other of its properties. If you ask for a proof of its power, see a ton of iron, hanging, like the fabled coffin of Mahomet, un-

supported, 'twixt heaven and earth, under the influence of magnetism, in the experiments of Dr. Page.

If, lastly, this bar of iron be thrown into a fire and the heat be urged by means of air blasts, the solid iron changes its physical state and becomes liquid. But if allowed to become cold again, it returns to its previous solid condition. I have already alluded to another change which iron experiences even by very slight variations of temperature: namely, its expansion by an increase of heat. Thus an alteration in its relative weight is effected, and its specific gravity is lessened. In both cases we have a temporary change wrought out in some previously existing property of the substance.

Such Forces as those illustrated by the last two examples the physicist claims as fit subjects for his investigations. These it will be noticed do not produce permanent change in all the properties of a body. He therefore groups them together. He speaks of the Force of Attraction; of Heat; of Light; of Electricity; and of Magnetism, as thus associated.

These illustrations might be multiplied to any extent, did time permit. But we pass to notice a theory of some value in this connection, though purely hypothetical.

Speculations on the constitution of matter have been offered from the earliest times. These hypotheses may be represented by that of Sir Isaac Newton, who considered matter to be composed of hard impenetrable particles, incapable of further subdivision.[1] Of Bishop Berkeley, who asserted that matter had no objective, but only a subjective existence.[2] And of M. Boscovich, a Prussian philoso-

[1] *Opticks* p. 375.

[2] "The existence of bodies out of a mind perceiving them, is not only impossible, and a contradiction in terms; but were it possible and even real, it were impossible we should ever know it." Berkeley, quoted by Dugald Stewart, in his *Philosophical Essays*, Edinburgh, 1855, p. 88.

pher, whose ground is intermediate. He maintains that matter itself is force.[1] Thus if you bring the mind in contact with any external object, by the medium of the senses, you can derive no idea of it beyond that which force produces. Take a stone for example. By the eye you discern form, color, roughness or smoothness, &c. But are not these all the result of force resident in that stone, which causes it so to reflect light to the eye? By the sense of touch you ascertain its hardness, its temperature, &c. But are not these all equally the effect of forces upon the senses? In short, forces are competent, either singly or in combination, to produce all the effects by which we gain our knowledge of matter. May we not then accept the hypothesis that matter is but a combination of the different forces, as at least possible? And that the differences we perceive in it, are caused by the varying proportion of these forces present? Force is as eternal as the truths of mathematics. How sublime then,—and the more so because comprehensible,—in this view of the case, appears the creation of the Universe. When the great fiat of creation went forth, the Forces came together by Almighty power and matter was. At the conclusion of all things how much more sublime will be the edict

[1] "The effects for example, which are vulgarly ascribed to actual contact, are all produced by *repulsive forces* occupying those parts of space where bodies are perceived by our senses; and therefore the correct idea that we ought to annex to matter considered as an object of perception, is merely that of a power of resistance, sufficient to counteract the compressing power which our physical strength enables us to exert."—*Boscovich, Theoria Philosophiæ Naturalis, Vienna*, 1758.

Upon this, Dugald Stewart remarks in the work just quoted, p. 93: "It can scarcely be denied, that the author or his commentators have been successful in establishing three propositions. I. That the supposition of particles extended and perfectly hard, is liable to strong, if not to insurmountable objections. II. That there are no facts which afford any direct evidence in support of it; and III. That there are some indisputable facts which favor the opposite hypothesis."

which resolves those Forces again into individuality, and matter itself shall vanish away. Thus,

> "The cloud-capped towers, the gorgeous palaces,
> The solemn temples, the great globe itself,
> Yea, all which it inherits, shall dissolve;
> And like an insubstantial pageant, faded,
> Leave not a rack behind."

Turning now to consider particularly some of these Forces, we will first notice Heat. This is perhaps the best known of nature's Forces. Man uses it more than any other for the accomplishment of his purposes. We have noticed already some of its effects upon matter. Its presence constitutes warmth; its absence, cold. Its manifestations are marvellously paradoxical. It exists in all bodies; even the coldest ice contains it, and will impart it to frozen carbonic acid. Not only is this true, but the zero or point of absolute cold has never yet been reached even artificially. Upon its presence, in greater or less amount, depends the condition of solidity, fluidity, or gaseity; the three great divisions of matter. By increasing sufficiently the heat, all substances may be converted into gas; by diminishing it all may become solid. Moreover if by any means we can force a solid to become a liquid, or more especially a gas, the heat necessary to the existence of the latter is absorbed and cold is produced. Upon this principle depend freezing mixtures. By the affinity of salt for water, it causes a solid ice to become liquid; cold is the result, and in this way ice cream is made. An admirable adaptation of this principle is seen in the machines for the artificial production of ice. In Liverpool, in the summer of 1860, I witnessed their operation. By an exhausting pump worked by a steam engine the atmospheric pressure was removed from the surface of ether, confined in a metal cylinder, placed horizontally in a tank of salt water. The ether flashed into

vapor, taking the heat necessary to its existence in this condition from the surrounding salt water, which was thus cooled down to 25° F. Salt water is used because it does not congeal at this low point. This water thus cooled, was then made to circulate round tinned copper boxes, containing pure water, which in a few minutes was frozen. The salt water in completing its round, gained only 5° or 6° of heat, and was returned again to the tank by a pump. The ether vapor, removed by the exhausting pump, was passed through a worm, coiled in a large cistern of water, and condensed to be again used. Thus by mechanical means heat is absorbed, cold produced, and ice made to the extent of *four tons* daily.

Conversely, if by any agency, we can reduce a gas to a liquid, or this to a solid, heat is evolved. A familiar illustration is afforded in the slaking of lime. Liquid water unites with caustic lime forming a solid hydrate, and a temperature of 570° F. is developed.

These facts prove that though a thermometer plunged in a solid, liquid, or gas, may indicate the same temperature, yet that the amount of heat in them is very different. Beside the heat sensible to the thermometer, we have hidden or latent heat, which is evolved whenever a change of state from the rarer to the denser condition takes place. Thus, when a ton of water is frozen, sufficient heat is evolved to raise another ton of water from 32° F. up to 174° F.: proving the paradox so often stated, that freezing is a warming process. When steam is condensed to a liquid, an enormous quantity of heat is set free. In this fact is found the applicability of steam for the purpose of heating our dwellings. While water may leave the boiler at 212°, its boiling point, circulate through the pipes and return, having lost but 5° or 6° of heat, steam leaving the boiler at the same temperature, will return water at the boiling point, the heat necessary to its vaporous condition, nearly

1000°, having been imparted to the air of the rooms through which it was conveyed.

But Heat is a Force; and the best evidence of this, is the expansion which it produces in all bodies. A bar of iron one square inch in section is stretched 1-10,000 of its length by a ton weight. The same elongation is effected by an increase of temperature of 16° F.[1] On heating an iron sphere from 32° to 212° F., Kussné found that its expansion exerted a force of 4,000 atmospheres upon every square inch of its surface; an amount equal to 30,000,000 pounds upon the whole. It is by such expansion that the rails upon our railways are frequently torn up. From Liverpool to Manchester, Eng., the rails are 500 feet longer in summer than in winter. If therefore allowance is not made for this expansion, serious accident may be the result.

But we must pass to the more subtle Force, Light. Who of us does not daily rejoice in the light, and yet who of us can tell with certainty what it is? Was Newton right when he maintained the emission theory; or Huyghens, when he proposed that of undulations? Of its origin we known only the Divine command, "Let there be Light." As says Milton;—

> "'Let there be Light' said God; and forthwith Light
> Ethereal, first of all things, quintessence pure,
> Sprung from the deep; and from her native East
> To journey through the airy gloom began,
> Sphered in a radiant cloud, for yet the sun
> Was not; she in a cloudy tabernacle
> Sojourned the while. God saw the Light was good,
> And light from darkness by the hemisphere
> Divided; light the day, and darkness night
> He named."

From our great central orb then, comes this Force. Thrown on nature and a thousand delightful forms start

[1] W. A. Miller, *Chemical Physics*, p. 178.

up as if by magic. Without Light what is the delicate blush of the rose or the magnificence of the landscape? What Michael Angelo's triumphs in sculpture or the exquisite coloring of a Raphael or Titian? From its home ninety-five millions of miles away, this beneficent agent comes forth to bless and to gladden mankind. Pure and white as the heavens from which it issues, it carries in its bosom all the colors and shades of earth. Moving at a velocity of nearly two hundred thousand miles in a second of time, it is yet composed of rays, undulating with various rapidities. Each ray is a color. Red, orange, yellow, green, blue, indigo, violet is the order in which they vibrate. While of red waves there are forty thousand in a single inch, of blue there are sixty thousand. As in two hundred thousand miles there are twelve thousand million of inches, and as this distance is passed over in one second, it follows that of red, there are four hundred and eighty million million, and of blue, seven hundred and twenty million million vibrations in a second of time. To see a source of light for one second requires the entrance of all these vibrations through the pupil. To see a red object, four hundred and eighty million million of waves must break upon the retina and throw it into vibrations as rapid as this. To see a blue, the retina must vibrate seven hundred and twenty million million times between two ticks of a common clock.

But how shall we demonstrate this omnicolored character of the light ray? If we pass a beam of white light through a prism, we find that on emerging it is composed of a series of colored bands, parallel to the axis of the prism, in the order already mentioned. This is called the Solar Spectrum, and it is due to the different degrees in which the different colors are refracted. Red is least bent, so it is found in nearly a right line with the original beam: violet is the most bent, so it is farthest removed

from that line. If instead of white light, we pass light of one color through the prism, we have a spectrum consisting of a single band of the same color. If there be more than one color we have bands, numerous according to the complexity. With purple light, for example, we should have a red and a blue band, widely separated. Thus the color, as well as the position of the bands, determines the identity of the colored rays. Certain chemical substances color flames. If these colors are analysed by the prism they give spectra more or less complex, but all distinctive of the substance used. We may then determine the character of a substance, by examining its flame with a prism. By the color and position of the bands given by the purple light above mentioned, we determine that potassa gave the color to the flame. This is Prof. Bunsen's new method of chemical analysis.[1]

But beside the colored bands of the solar spectrum, there are other and dark bands. Fraunhofer investigated them and named them by the letters of the alphabet. One of the most prominent of these lies in the brightest portion of the yellow band. It is called Fraunhofer's line D. Now a flame colored by sodium gives a yellow band precisely in the same position. Can we make this yellow line dark? By placing a strong white light, as that of the electric arc, behind the yellow flame, there is a spectrum produced, in which this yellow band is replaced by a dark one. The yellow flame has absorbed all the yellow from the white light behind it; the space which this color occupies in the spectrum is therefore dark. This is the great discovery of Kirchhoff. It is, to use his own words, the fact that "a flame absorbs rays of the same refrangibility as those which it emits."[2] Upon this discovery

[1] Poggendorff's *Annalen*. Bd., cx, 1860.

[2] *Researches on the Solar Spectrum, &c.* Translated by Roscoe, London, 1862, p. 14.

Kirchhoff originated one of the most brilliant generalizations ever recorded in science. If, said he, we can produce the dark band D, by placing an intense light behind a sodium flame, is not that line in the solar spectrum so produced? In other words, is not the sun a solid body, intensely luminous, surrounded by an atmosphere of the substances composing it, in vapor, one of which is sodium? Other dark lines were compared in this way, and he ascertained the identity of solar bands with those produced by the metals calcium, magnesium, barium, iron, nickel, copper, chromium, and zinc. These metals exist therefore in the sun.[1] The light of the stars has also been subjected to the same rigid analysis. Their composition varies from that of the sun, and they differ among themselves.[2] So from our little planet does the chemist, standing side by side with the astronomer, reach out his hand to grasp these distant orbs, and to analyse them by that light which has been tens and perhaps thousands of years on its way to reveal its secret.

But has the light of our sun no other mysteries? Has it no other qualities than those mentioned? It gives us light: does it do no more? Witness that curious, that almost magic art, by which in a second of time, the shell bursting in the air, the crowded thoroughfare, with its whirl of life, or the lineaments of the human face may be accurately transferred to paper. From whence comes the power to effect this? In the light which comes to us from our sun, we find not only rays giving light, but also chemical or actinic rays, and heat or calorific rays. In the spectrum the maximum of heat, when a glass prism is used, is in the red; of light in the yellow; and of chemical power in the violet. We can therefore isolate each of these by screens

[1] Kirchhoff, Op. Cit., pp. 20, 21. Also *Phil. Mag.*, Aug., 1860.

[2] L. M. Rutherfurd, *Sill. Am. Jour.*, 2d series, vol. xxxv, p. 71.

of colored glass. By means of glass colored yellow with the oxide of silver, we can cut off both the actinic and the calorific rays, while the intensity of the light rays is but slightly diminished. If we use a glass colored blue with oxide of cobalt, the actinic rays freely pass while the heat and light rays are stopped. Lastly, if a red glass colored by suboxide of copper be used, the heat rays permeate it freely, while no passage is afforded to the actinic rays, and only a feeble light is transmitted. It is a well known fact that a photograph can be taken with as much facility in a room whose windows are of deep blue glass, even though to ordinary appearance it be entirely dark, as in one open to the full light of day. This principle of screening off the rays is of great practical value to the horticulturist. Seeds in germinating need chemical power to convert their starch into sugar. When therefore the florist wishes to force his seeds, he covers them with a dark blue glass. As they advance in maturity, they need light rather than actinism.[1] The blue glass is therefore removed, the yellow substituted and the vigor of growth continues. When the time of fruiting comes, heat becomes more essential. A red glass takes the place of the yellow with equally good results. Thus by following the needs of the plant, he is successful. Had he used the colors inopportunely the plant must have perished.

This composition of sunlight is therefore for a beneficent purpose. Mark now its beautiful adaptation to the varying condition of vegetation. If you ask the practical operator, he will tell you that the best season of the year

[1] "It was long a question whether the decomposition of carbonic acid by plants was due to the luminous or to the chemical rays. It is now clearly established that the luminous rays are the most active in producing this effect; which they do indirectly by exciting the vital powers of the organized structure."

Poetry of Science, by Robert Hunt. London, H. G. Bohn, 1852, p. 182.

for photography is the spring. When all the rich green of our fields is yet unfolded from the embryo, then it is that a large excess of actinic power is concentrated in the light of the sun. But vegetation advances and what just now was the germ has become the plant. Increased light is necessary to continue its growth, and lo, the sun beams forth with a brighter glow and it is accomplished. Autumn advances upon summer, and the object of the plant's existence is yet to be attained. It is to yield seed to reproduce its kind. To ripen this fruit, to perfect this seed, increased heat is essential. And again the sun adapts itself and furnishes it. Relatively to the light and chemical power, the heat is at a maximum in the fall of the year. Can we have better evidence than this of design in nature? [1]

But another of these subtle agencies awaits our notice. It is Electricity. See the ancient philosopher of Greece as he rubs the little piece of ηλεκτρον, presents it to bits of pith, and notices how they are attracted. Watch the peculiar satisfaction with which this singular property was ascribed to the agency of minute insects, which threw out invisible tentacles or claws and drew up the pith. But the world slept on for twenty centuries, while this wonderful agent lay unborn. Then behold it touched into life in England; see its rapid strides of progress, passing at a bound from the cradle to manhood. Gradually its innermost secrets are brought to the light of day and applied for the good of man. Mankind honor Franklin equally because "Eripuit cœlo fulmen," as well as "sceptrum tyrannis." Who, standing by that great philospher, could have comprehended the vast benefit to the world of that kite experiment, when he led the lightning captive on the string and drew it harmlessly from the key? Now every house may rear its gilded point to the skies; and, as the

[1] Robert Hunt. Op. Cit., p. 374, et seq.

lightning's venom is withdrawn, fear passes and all is safety and happiness. But the eighteenth century is drawing to its close and a professor of anatomy at Bologna is busy in his laboratory, striving to ascertain the nature of that vital force with which organic beings are endowed. Instead of this, however, he stumbled upon a fact which in its practical bearings was of far more importance. Blind, save to his one cherished idea, he would not see the prize within his grasp. It was reserved for his talented pupil and nephew to develop it into a science. And from Volta's pile, as an ancestor, how numerous are the posterity. The methods of generating this peculiar power are almost infinitely varied to answer their numerous applications. And to-day, as a direct gift from Volta, Maine can converse with California, "as a man talketh with his friend." To the development of this wonderful force, we owe a thousand of earth's blessings. The arts of mining and metallurgy, of civil engineering and of military tactics, out of hosts of others, claim its daily assistance. And as it comes forth, crowned already with laurels, to take its place among the sciences, it has a consciousness of power, which though yet latent, is destined to achieve still greater results for humanity.

Let us notice some facts concerning this power which have already been revealed. The electricity of the thunder cloud carries power as does the English locomotive, small in amount but of enormously high pressure. While that of the telegraph seems more like the energy of the Great Eastern, of low pressure, yet vast in amount. It is evident that an equal amount of work may be done by water whether it falls in a small stream from a great elevation, or rushes in a mighty torrent over a dam but a few feet in height. In the former case we illustrate the electricity of friction. In the latter that of chemical action. The former moves at the astounding velocity of two hun-

dred and eighty-eight thousand miles in a second.[1] The latter more slowly, being as low as eleven thousand miles.[2] The distance through the air which the spark will traverse, depends upon the *pressure* or tension. The magnetic effect of this agent, on the contrary, has reference to the *amount* of Electricity which circulates. The Electricity which is excited by rubbing a glass tube with a silk handkerchief, will easily pass across half an inch of space; while the great voltaic battery of Mr. Children, consisting of twelve hundred and fifty pairs of plates, was unable to project a spark one-fiftieth of an inch through space.[3] But on the other hand, a piece of copper and of zinc, the size of a cent, will produce a magnetic effect far beyond that which is given by the most powerful discharge of frictional electricity ever obtained. Mr. Whitehouse, in experimenting upon the Atlantic cable, sent a message through one thousand miles of it, submerged, with the power generated by a voltaic element consisting of a silver wire and a zinc wire the size of a pin, excited by a drop of acid, supported between them by capillary action.[4] The electricity of friction is therefore characterized by its intensity, and that of chemical action by its quantity.

We have called electricity a force. Let us hear the greatest living philosopher, Mr. Faraday, upon this point. "The quantity of electricity," says he, "required to decompose one grain of water is equal to eight hundred thousand discharges of an electrical battery, exposing thirty-five hundred square inches of surface, charged with thirty turns of a powerful electrical machine."[5] That is, to decompose one grain of water requires the electricity from a charged surface of four hundred acres, which amount is

[1] Wheatstone, *Phil. Trans.*, 1834, p. 589.

[2] Silliman's *Physics*, 2d edit., p. 538.

[3] Gmelin's *Chemistry*, Vol. I, p. 418.

[4] *Chambers' Journal*, 2d series, Vol. VIII, p. 122.

[5] Faraday, *Experimental Researches in Electricity*, Vol. I, p. 253.

scarcely exceeded in the heaviest thunder storm. If this were spread upon a cloud two-thirds of a mile distant from the earth, it would exert an attractive force of sixteen hundred and sixty-four tons! If we could attach the atoms of oxygen in this grain of water to one thread one twenty-fifth of an inch long, and those of hydrogen to another, the force required to separate the threads in one second of time would be 7,250 tons! Yet this is easily accomplished on the lecture table.

Closely connected with this is another force to which we must refer briefly. I allude to magnetism. In the town of Magnesia, in the province of Lydia, Asia Minor, is a black ferruginous mineral, which, from remote antiquity, has been known to possess the property of attracting to itself small bits of iron. From the locality where the mineral was discovered the property gets its name, magnetism. In our own northwest, large beds of this ore seriously interfere with the ordinary methods of land surveying. If this ore be rubbed upon a steel needle, we find that the property is communicable, and that if the needle, now a magnet, be carefully laid upon the surface of water, it will arrange itself in a direction nearly parallel with the axis of the earth. Moreover we find that the end of the needle toward the north pole of the earth is repelled by the same end of another needle similarly prepared, while it is attracted by its opposite end. We conclude then that the earth is a great magnet. Proceeding upon this supposition, M. Gauss has calculated that the magnetism of the earth is such as would result from the existence of six magnetized steel bars, weighing one pound each, in every cubic yard of its mass. Compared with one such magnet, the earth's magnetism is represented by 8,464,000,000,000,000,000,000.[1] There is evidence of power in the amount which a steel magnet made

[1] Prof. Faraday, *Annual of Scientific Discovery*, 1852, p. 111.

in the manner indicated would sustain. Sir Isaac Newton wore in his finger-ring a piece of lodestone which, though its weight was only three grains, was yet able to lift seven hundred and sixty grains.[1] Ordinarily steel magnets can not in this manner be made to sustain more than twenty-eight or thirty times their own weight.

There is still another force inviting our examination which, in the extent of its range of action, or in the wonderful results which it produces, is not surpassed by either of those already considered. This force is chemical affinity. What more mysterious than those transmutations which it effects? What more paradoxical than many of its facts? Yet to its unceasing energy we owe our existence; even the world about us was formed by this force, and is now held together by it. What its essence is we can not say, but its effects we daily witness. Even in the very constitution of matter we detect it. The pure water, so essential to life, whether taken from the frozen north or the parched tropic, shows by its uniform eight parts of oxygen to one of hydrogen, that one single force orders its formation. Every mineral, every plant, every animal has its components brought together and united by chemical affinity. But it is when this force brings about a change in matter that the results are most stupendous. See the people of Lisbon rushing frantically from their tottering houses to be slain by falling timbers and stones in the streets, during the great earthquake of 1755, if you would understand the power of chemical action. Witness Vesuvius putting herself in martial array and hurling fiery lavas from her arsenal to overwhelm Herculaneum, or clouds of cinders and scoria to cover the city of Pompeii, if you would comprehend its energy. But the cause of these changes is none the less powerful because silent. Working thus quietly it achieves its noblest triumphs. Consider the fern forests of the carboniferous age. See

[1] Silliman's *Physics*, 2d ed., p. 530.

that rank vegetation covering half our continent, soon to be overwhelmed in one of those vast cataclysms of nature, and covered with sand and gravel. Now chemical force lays hold of the woody fibre and, at the depth to which it is buried, converts it into coal. How vast this action was appears from the fact that, were the present consumption of the world to be quadrupled, and the enormous amount of four hundred million tons of coal used annually, the amount of this material in our own country would supply the demand for ten thousand years. And yet this action was silent and gradual.

But, again, how has chemical force enriched mankind! Every day brings numberless blessings which this agent has conferred. The light which streams upon us as we wake in the morning passes through glass made by a chemical process. The linen with which we clothe ourselves has been bleached by it. The bread upon our breakfast table depends on chemical force for its lightness. Our improved stoves are made as its laws have dictated. The morning paper has come to us from pulp which it has whitened, and with characters printed with ink of its suggestion. The elegant colors which we use to decorate our houses and our persons it has unfolded. The dazzling Florence white of the inside paint reciprocates its effect with the brilliant hues of the wall paper. The magenta, mauve, roseine, azuline and bleu de Paris of our silks have been called forth by its magic wand from coal tar, only to look upon the Berlin blue, ultra marine and carmine of the artist, from a scarcely less ignoble origin. The delicate flavors of the table, as well as the perfumes of the toilet, have been evolved under its direction. In every department of household economy, alike in the drawing-room and in the kitchen, its assistance is invoked. It has carried man on in civilization, and civilization has in turn sustained its labors, until man has well nigh attained the summit of perfection.

Turn we now to consider a little more fully the nature and origin of force. If I were to state that matter is indestructible, I should utter a simple truism which is familiar to every one before me. Though protean in its appearance, matter ever remains the same in essence. Indeed since the creation of the earth not one particle of matter, if we except aerolites, has been added to or taken from its mass. The fuel we burn in our stoves passes up the chimney as invisible gas, but carries with it the entire weight of the material consumed. If a piece of gun cotton be placed in a globe previously exhausted and weighed, on flashing it by means of electricity there will be no change in its weight. Though by the action of chemical force matter may disappear and may seem to be destroyed, yet by this same force we can cause it to reappear with all its original characters. But that force is subject to the same law; that force is never lost; and that the store of force in our universe is the exact equivalent of that which it contained when it was first ushered into existence, these are facts not as commonly accepted. Can we not then annihilate force? I reply no, no more than we can matter. A house may be destroyed by fire, but not the matter of which it is composed. So the form in which the force appears may be changed, but the force itself reappears in some other form and as truly exists as before. We can make the statement more apparent by a few illustrations, and we will use mechanical force or motion as the starting point, because with it we are best acquainted. If a blow be struck upon an anvil by a hammer, the force of the blow is received by the anvil and appears lost. If a rifle ball be projected against a rock, its force is spent apparently without effect. If a stone fall from a height, it strikes the earth and its force seems annihilated. Now can we trust the first appearance in these cases? By no means. By careful scrutiny we

shall discover that the force which seems lost has only changed its state. It is indeed lost as motion but it appears as heat. The blacksmith by continuing his blows soon makes the iron hot. And if the rifle ball be carefully examined it will show signs of fusion. But not only can we make these statements in general terms, but we can estimate the relation with mathematical precision. If we allow a leaden ball to fall from a height of twenty-six feet to the earth, its motion will be stopped and converted into heat, which, were it all concentrated in the ball, would raise its temperature one degree, Fahrenheit.[1] The force with which a body strikes the earth depends upon the height from which it falls. The height to which a body rises, when thrown upwards, is as the square of its velocity. Therefore the force with which it strikes, and the consequent heat generated, is as the square of the velocity. The same principles hold true if we use gunpowder as the moving force. Hence it follows that if we double the velocity of a projectile we increase the heat generated, when its motion is arrested, fourfold. If we treble its velocity we augment the heat ninefold, and so on. Now if the rifle ball just referred to fell by gravity through 772 feet, its velocity would be 223 feet per second. If this motion were suddenly arrested, and all the heat were collected in the lead, its temperature would be elevated thirty degrees, Fahrenheit. But when thrown by gunpowder six times this velocity, or 1,338 feet a second, would not be inordinate. With six times the velocity, 6^2 or thirty-six times the amount of heat, or 1,080°, Fahrenheit, would be generated. Were this heat all retained in the bullet it would be far more than sufficient to fuse the lead. If a ball of iron be used, the temperature to which it will be raised is only one-third of this,

[1] Prof. John Tyndall, *Heat considered as a mode of motion*, Am. edition, p. 55.

because its capacity for heat is greater in this ratio.[1] Still, in the experiments with the Whitworth gun in England, a bright flash of light appeared when the hexagonal eighty pound bolt struck the iron target, as if a gun had been fired in return; and the bolt when found in the interior was too hot to handle.

What we have now shown to be true of falling bodies and of projectiles, is true of mechanical action of any sort, and with the same result. The attendant neglects to oil the axle bearings of our railway cars. Presently they begin to smoke, the train lags, and soon after the car is in flames. That force, which, suitably applied would have hurried the train onward, is lost by friction and converted into heat. Count Rumford caused a cannon to revolve against a blunt borer, the whole being immersed in water. In two and a half hours the water boiled.[2] This is also true of compression. A piece of wood suddenly and strongly compressed in the jaws of a vice becomes hot. And I need hardly refer you to the familiar experiment with the fire syringe to prove the same principle. In all the cases adduced, we have mechanical force apparently lost but really converted into heat. And the one is the exact equivalent of the other.

Now what is true of mechanical force, is true of all other kinds of force. All of these Forces of nature are thus transmutable. Suspend their manifestation in one direction, lo! it appears in corresponding quantity in another. We cannot extinguish force. Whatever form it assumes, it is only one of many in which it may show itself. And if this be true, it is also true that no force can be lost. In one form or another, the force of the universe is preserved to undergo transmutations to the end of time.

In the light of the statements which have thus far been

[1] *Ibid*, p. 56.

[2] *Phil. Trans.*, 1798, p. 80.

made, how different do the forces which we have considered appear? Let us notice them now in their relation to each other, viewed from our new standpoint. We have seen that mechanical force as motion, is, when arrested, converted into heat. This leads us to inquire, what is heat? Is it material, as the older philosophers considered it? Or is it merely a property of matter and itself immaterial? This was answered by Sir Humphrey Davy, in his first scientific memoir, as follows:—By the friction of two pieces of ice against each other at a temperature below the freezing point, these were melted. As the capacity of water for heat is greater than that of ice, the heat produced did not come from the water obtained, by virtue of a diminished capacity. Of course in the case of ice, it could not have come from oxidation. By producing friction in a vacuum, he demonstrated that the heat of fluidity did not come from the ice nor from surrounding bodies by conduction. But if heat be material, these are all the ways possible by which the water could have obtained it. Now the heat of friction may be produced to infinity. In view of these facts, he says, "It is evident that caloric, or the matter of heat, does not exist."[1] We come to the other theory therefore and, for reasons already implied in speaking of the conversion of motion into heat, conclude that heat itself is motion. When a ball falls through the air and produces heat by its sudden stop, that which was motion of the mass has become motion of the molecules, or in other words, heat. Heat is therefore molecular motion, a property of matter rather than matter itself. Hence it is easy to see how the intensity of motion determines the intensity of the heat produced. And also the converse of this proposition: that molecular motion may be reconverted into mass motion. Mr. Joule of Manchester, England, has been experimenting since 1843 to

[1] *Works of Sir Humphrey Davy*, Vol. II.

determine practically the ratio of heat to work; and by causing paddles to revolve in water, oil, or mercury, by the descent of known weights, as well as by other means, he concludes that a weight of 772 pounds falling through one foot, produces sufficient heat to raise one pound of water one degree F. The term "foot pound," is used to indicate the lifting of one pound one foot high. 772 foot pounds, therefore, is the mechanical equivalent of heat.[1] This constant may be applied to the solution of many interesting problems. "Whenever work is done by heat, heat disappears. A gun that fires a ball is less heated than one that fires a blank-cartridge," says Mr. Tyndall. The statement that heat may be reconverted into mechanical force receives its exemplification in every steam engine.

In these facts we have important examples of what Mr. Grove calls the "Correlation of Forces," meaning by this term their mutual convertibility. Let us therefore go a step farther and see how far the forces we have spoken of are convertible into each other. Starting with mechanical force, we have seen in every case that it may be converted into its equivalent of heat. The same is true of the force we call Chemical affinity. When carbon combines with oxygen, we have heat developed. And this development is the same in kind with that produced by the fall of a body to the earth; but in the one case we have collision of sensible masses, in the other of atoms. "Could we measure the velocity of the atoms when they clash; could we find their number and weight, multiplying the weight of each by the square of its velocity and adding all together, we should get a number representing the exact amount of heat developed by the union of the Oxygen and the Carbon."[2] Hence the production of heat by chemical action

[1] J. P. Joule, *Phil. Trans.*, 1850, p. 61.

[2] John Tyndall, *Lecture on Force, delivered June* 6, 1862, *at the Royal Institution.*

must be regarded as simply *a change in the direction and character of atomic motion.* The amount of heat developed in this way we are accustomed to consider enormous, simply because it is most familiar to us. But it does not equal that produced by arrested mechanical force. "One pound of coal in combining with oxygen, produces an amount of heat which, applied mechanically, would raise a weight of one hundred pounds to a height twenty miles above the earth. Conversely one hundred pounds falling from a height of twenty miles and striking against the earth, would generate an amount of heat equal to that developed by the combustion of a pound of coal."[1] But from the data we have, we can compare on a larger scale, combustion and mechanical force as heat producers. Our earth moves 68,040 miles an hour in her orbit. If this motion should suddenly be stopped, sufficient heat would be developed, according to Mayer and Helmholtz, to raise a globe of lead the same size, 384,000° C. or 691,200° F. This would not only reduce our entire earth to fusion, but dissipate it for the greater part in vapor. This amount of heat would require for its development the combustion of fourteen globes of solid coal, each equal to the earth in size. If now, as would necessarily be the case, the earth should fall into the sun, the heat developed would equal that produced by the combustion of sixty-four hundred and thirty-five worlds of solid carbon!

But perhaps the most striking exemplification of the power produced by chemical action, through the medium of heat, is to be found in the various stages of the existence of water. Premising that Count Rumford determined that one pound of hydrogen in combining with eight pounds of oxygen to form water, evolved sufficient heat to raise 34,000 pounds of water 1° C., I go on to quote Mr. Tyndall. "First, we have the constituents of water as free atoms,

[1] J. Tyndall, *Lecture on Force.*

which attract each other, fall, and clash together. The mechanical value of this atomic act is easily determined; knowing the number of foot pounds corresponding to the heating of 1 lb. of water 1° C., we can readily calculate the number of foot pounds equivalent to the heating of 34,000 lbs. of water 1° C. Multiplying the latter number by 1,390 (the number of foot pounds corresponding to 1° C.) we find that the concussion of our one pound of hydrogen with eight pounds of oxygen is equal in mechanical value, to the raising of 47 million pounds 1 foot high! * * * * After combination the substance is in a state of vapor, which sinks to 212°, and afterwards condenses to water. In the first instance, the atoms fell together to form the compound; in the next instance, the molecules of the compound fall together to form a liquid. The mechanical value of this act is also easily calculated: 9 lbs. of steam in falling to water, generate an amount of heat sufficient to raise 967×9=8703 lbs. of water 1° F. Multiplying this number by 772, we have a product of 6,718,716 foot pounds as the mechanical value of the mere act of condensation! The next great fall of our 9 lbs. of water is from the state of liquid to that of ice, and the mechanical value of this act is equal to 993,564 foot pounds. Thus our 9 lbs. of water, in its origin and progress falls down three great precipices: the first fall is equivalent to the descent of a ton weight urged by gravity down a precipice 22,320 ft. high; the second fall is equal to that of a ton down a precipice 2,900 ft. high; and the third is equal to the descent of a ton down a precipice 433 feet high. I have seen the wild stone avalanches of the Alps, which smoke and thunder down the declivities with a vehemence almost sufficient to stun the observer. I have also seen snow flakes descending so softly as not to hurt the fragile spangles of which they were composed; yet, to produce from aqueous vapor, a quantity of that tender material

which a child could carry, demands an exertion of energy competent to gather up the shattered blocks of the largest stone avalanche I have ever seen, and pitch them to twice the height from which they fell."[1]

To return to our Forces. Light, also, may be converted into Heat. In the view of many distinguished philosophers, none of the sun's direct heat reaches the earth. As both light and radiant heat are the same in essence, being vibrations, it is maintained that if these vibrations rise to the enormous rapidity already mentioned, they are competent to affect the optic nerve and produce the sensation of light. If they are less than this they affect only the nerves of general sensation and produce the impression of heat. Now, light waves may be so reduced in the rapidity of their vibrations by passing through certain media, that they become heat waves. Dr. Franklin long ago placed pieces of the same kind of cloth, but of different colors, upon the snow and watched the order in which they melted the snow beneath them. He found that this order was precisely that in which they absorbed the light. Black destroys all light waves. But it is thereby heated and is found deepest in the snow. Next came blue, green, purple, red, and yellow. White reflecting all the light rays, remained on the surface.[2] On the other hand, it is maintained that the heat from luminous bodies is of two kinds: luminous heat rays, and obscure heat rays. That the former alone accompany the sunlight across space and are converted into obscure rays by absorption in our atmosphere and on the earth's surface. These obscure rays can not then pass back again and are retained. As many of the heat rays from a bright coal fire, being luminous, pass through a glass screen, while those from a steam

[1] J. Tyndall *on Heat, &c., Am. Ed.*, pp. 163, 164.

[2] Cooke's *Chemical Physics*, p. 653.

radiator, being obscure, are entirely intercepted: so the atmosphere, by allowing the rays of light, according to one theory or luminous heat rays, according to the other, to pass freely through it, while it intercepts the obscure heat rays, into which the former are converted by absorption on the earth's surface, acts like a mantle to our globe, protecting it against the intense cold of the celestial spaces through which we are so rapidly whirling.

Conversely, we have only to intensify the vibrations of the rays of heat to produce light. This we can do by exposing a piece of platinum wire to a source of heat, gradually increasing in intensity. At first only obscure heat rays are radiated. Then the deepest red becomes visible, the very color whose vibrations are slowest. As the heat increases orange appears, then yellow, until a full white heat is reached. And if this be intensified a distinct blue can be seen.[1] This experiment strengthens our conviction that the waves of heat and light differ from each other only in intensity.

Electricity may be converted into heat. This is effected precisely as in the case of light, by lessening the vibrations. Whenever we cause electricity to traverse a poor conductor heat is evolved. In the case of lightning it is not when the electricity passes along the metallic conductor that any danger is apprehended. If this conductor be continuous and large enough, we may sit with perfect safety upon a barrel of gunpowder through which it passes, during a thunderstorm. It is when the rod is broken, and the lightning is caused to pass through a poor conductor, air, that it is converted into its equivalent of heat. Any combustible in the vicinity of the spark is inflamed. A common lecture experiment is the firing of gunpowder by the spark. This can only be effected by interposing an imperfect conductor, as a wet string, in

[1] Prof. Bunsen, *quoted in Brande & Taylor's Chemistry*, p. 97, Am. ed.

the circuit. The string lessens by its resistance the rapidity of the waves, lowering them to heat. The tension of voltaic electricity being low it can not pass through air. Its heating effect is produced when a wire of platinum, the metal offering most resistance, is placed in the circuit. In this way submarine blasting is effected. The fine platinum wire between the electrodes is immersed in the powder. When it becomes red hot this is exploded.

Conversely, heat may be converted into electricity. Prof. Seebeck, of the University of Berlin, first developed this fact. If an iron poker be placed in the fire, a passage of heat from the hot to the cool end takes place. But at the same time a current of electricity flows in the other direction. If two bars of different metals be soldered together at one end, and the junction be heated, a current of electricity is set in motion from one to the other. Bars of bismuth and antimony give the best effect. If the electricity be measured by a delicate galvanometer, we have an apparatus for indicating slight variations in temperature far superior to any other. By its means Prof. Melloni made his masterly researches on heat. He was even able to determine the relative heat of insects.

Magnetism may be converted into heat. A flat disc of copper, caused to rotate between the poles of a powerful magnet, speedily becomes hot. Fusible metal may thus be melted.[1]

If a bar of iron, placed as the armature of a powerful electro-magnet, be rapidly magnetised and demagnetised by charging repeatedly the magnet, which is kept cool by a current of water, its temperature will be raised.[2]

[1] J. P. Joule, *Phil. Mag.*, 1843, pp. 355 and 439; also Tyndall *on Heat*, p. 51.

[2] W. R. Grove, *Correlation Physical Forces*, p. 159.

Electricity may be converted into light. If the electrical vibrations which produce heat are sufficiently exalted they produce light. When a spark passes through space it is luminous. If the electrodes of a powerful voltaic series terminate in carbon points, and these after being in contact are slightly separated, even in a vacuum, the passage of the electricity announces itself by the most intense light which art can produce. If ninety-two carbon elements be arranged in two series of forty-six each, the light emitted is equal to that of 1,144 candles, according to M. Despretz. It is to the light of the sun as 1 to 2½. On the evening of the last Fourth of July, a light of this sort, produced by 250 couples, was projected from the cupola of the State House in Boston in presence of Profs. Cooke, and W. B. Rogers, which the latter calculated was equal to that of ten thousand candles.

Electricity may develop electricity. If near a wire conveying a current of electricity, and parallel but not in contact with it a second wire be placed, the ends of which are connected with a galvanometer, it will be noticed that whenever the circuit is broken or closed the galvanometer needle is deflected by the passage of a current in the second wire. This principle, discovered by Mr. Faraday, has been expanded by Prof. Henry, who has obtained currents of the ninth order, eight of which were entirely independent of the battery. Moreover by varying the size of the second wire we may obtain in it either a quantity or intensity current at pleasure.

Electricity may produce magnetism. Prof. Oersted, of Copenhagen, observed that when a wire connecting the terminals of a battery was placed parallel to a magnetic needle, the needle instantly moved from its position and attempted to place itself at right angles to the wire. If a piece of iron rod be placed in the latter position it became

magnetic. This effect is increased by coiling the wire round the rod, because in this case every coil is nearly at right angles to the rod, and every coil adds to the result. Such magnets are called electro-magnets, and they have been made of enormous power, capable of sustaining a ton and more. But not only does the iron become a magnet: the coil also acquires the property. If the bar be partially withdrawn and then released, it flies back into the centre of the coil. Mrs. Somerville, who first noticed this fact, suspended a sewing needle in the centre of a coil without visible support. This has been named the axial magnetic force, and at present affords the only means of applying this agent mechanically. Dr. Page ran a train of three passenger cars from Washington to Bladensburg some years since by the application of this force, attaining a speed of nineteen miles per hour.[1] There is no known limit to the force thus produced. Its expense alone limits its application.

Conversely, magnetism may be converted into electricity. Mr. Faraday observed that when a coil of wire, the ends of which touched each other, was placed on the armature of a powerful steel magnet, and this armature placed upon or taken from the poles, a spark was visible between the ends of the coil. And now the force thus generated is being applied to the telegraph. The alarms of fire in Boston are struck by the force derived from coils revolving between the poles of powerful magnets.

But electricity can produce chemical action. If a piece of paper, moistened with a solution of iodide of potassium, be placed between the electrodes, the paper will be stained brown from the iodine set free. And now this principle, expanded in the electrotype is used for a thousand purposes. Our books are printed from electrotyped

[1] *Annual of Scientific Discovery*, 1852, p. 99.

plates. Our table ware is silvered, and patent watches are gilded, by this process. If water be thus decomposed in a close vessel the force generated is enormous. Mr. Gassiot has ruptured iron cylinders an inch thick in this manner.[1]

That chemical action produces electricity I need hardly stay to affirm, for it is the very means by which this powerful agent is evolved. Whenever chemical action of any sort takes place, whenever changes take place in the composition of matter, this subtle force is set free. Says Mr. Faraday, "The amount of electricity set free by the chemical action of a grain of water on four grains of zinc is equal to that evolved in a very heavy thunderstorm," and he is the world's best authority.[2]

Nor need I stop to prove that chemical action produces light. We have such abundant evidence on every hand that to make a formal statement of the fact is to utter a commonplace. Every cottage has now the friction match wherein mechanical force is converted into heat; heat produces chemical action, which in its turn produces the heat and light of combustion. The poorest peasant has at hand the means of producing light, which but a few years since the richest noble could not obtain. The old tinder box is laughed at in this nineteenth century, yet it contained the same principle, though in the germ.

Light produces chemical action in a thousand ways. Every amateur in chemistry has exposed mixed hydrogen and chlorine gases to the sunlight to witness their explosive union. And every one of us has had an "impalpable scale," in the language of Dr. Holmes, taken from his face in the shape of a photograph. Every *carte-de-visite* given or received by the hand of friendship is a silent witness to the chemical action produced by light. The sun is now our greatest artist.

[1] *Tyndall on Heat*, p. 94, note.

[2] Faraday, *Experimental Researches*, Vol. I, p. 257.

We have thus taken somewhat in detail the facts which establish the mutual convertibility or "correlation" of forces. And to my own mind they satisfactorily prove the proposition made at the outset, that force is never lost; but though it may disappear in one form it reappears in another, and in exactly equivalent amount.

We might go a step farther and show that frequently more than one form of force is developed at the same time, and that it is owing to this fact that it is so difficult to estimate the value of any one force in terms of another. One experiment of Mr. Grove is so striking and so conclusive that I must beg leave to describe it. "A prepared daguerreotype plate is inclosed in a box filled with water, having a glass front with a shutter over it. Between this glass and the plate is a gridiron of silver wire; the plate is connected with one extremity of a galvanometer coil, and the gridiron of wire with one extremity of a Breguet's helix — an elegant instrument formed by a coil of two metals, the unequal expansion of which indicates slight changes in temperature — the other extremities of the galvanometer and helix are connected by a wire, and the needles brought to zero. As soon as a beam of daylight or of the electric light is, by raising the shutters, permitted to impinge upon the plate the needles are deflected. Thus *light* being the initiating force, we get *chemical action* on the plate, *electricity* circulating through the wires, *magnetism* in the coil, *heat* in the helix, and *motion* in the needles." [1]

It was stated a few minutes since that the store of force in the universe has not diminished since the creation. But it must be apparent to all that the earth, in common with the other planets, is continually losing heat by radiating it into space: and that unless this loss is made up, our globe will soon be barren of life. That this loss is com-

[1] *Correlation of Physical Forces*, London, 1855, p. 120.

pensated, appears from the following facts. We have seen that when bodies cool, they contract. Rotating bodies which contract, revolve more rapidly. It has been proved by M. Laplace that the time of rotation of our earth has not diminished 1-300 of a second for the 2,000 years since the time of Hipparchus. Hence we conclude that it has not lost heat. If I ask whence the supply, I am instantly referred to the sun. According to the estimates of M. Pouillet, the earth receives annually from the sun, sufficient heat to melt 5,400 pounds of ice upon every square foot of its surface; if, therefore, the globe were entirely covered with a shell of ice 100 feet thick, it would be melted by the sun in a single year.[1] Thus so far as the heat of the earth in concerned, we see that its source is the sun. But perhaps we can prove that this is true for all force upon the earth.

Go to any one of those thriving manufacturing villages, scattered all over our land. There your eye rests on massive six story buildings, from whence emanates the whirring of machinery. You enter, and from garret to cellar, all is one incessant rattle. Passing in at that door are immense bales of cotton, to be seized, picked to pieces, and carded; the fibres being laid parallel, they are divided and by a million of steel fingers, twisted into threads, to be then spun into different fabrics. And as you pass from floor to floor and wonder at the skill displayed in this mechanism, you ask the source of the power which renders it all available. You are pointed to an open door, within which you perceive an immense wheel, into whose buckets water is constantly pouring, causing them to descend and bring others to the task. The power you see comes from falling water. But how was it raised? Passing out of the cotton-mill you are shown the canal, by means of which, the water from an adjacent stream is led

[1] Pouillet, *Physique Experimentale*, Paris 1856, Tome 2, p. 714.

to the water wheel. You walk up along the banks of this stream. Here and there it receives tributary rills, grows smaller as you ascend, till a clear bubbling spring reveals its source. Is not this water a gift to the spring from the clouds? And was it not from the ocean and the lake that the beams of the sun lifted it invisibly to the clouds? Is it not a part of the sun's force then, which gives life to the machinery of the mill?

But again. Go down upon one of the wharves of our metropolis and behold that huge ocean steamer. The hour for her departure has come. The last bell has rung, and as you look she moves slowly from her moorings and without a sail, passes majestically the forts, through the Narrows and out upon the broad Atlantic. Boldly she buffets the waves, and though the tempests may wreak their vengeance upon her, steadily she moves on her way, carrying safely to the goal her cargo of life. If you ask the means by which this is accomplished you are pointed to the enormous paddle wheels; but in them alone there is no power. You see on board of her a huge mass of machinery, complicated, but motionless. Not far from it are iron tanks full of water; but they are equally impotent. What shall give energy to all these appliances? That black and dirty coal, which just now you shrank from being defiled by, contains a power in its embrace which is competent to the task. Placed in the furnace and ignited, and water, machinery, and paddle wheels are its servants, while it bows its head to the will of man alone. Do you ask whence the coal obtained its power? I refer you to those past ages, when our earth was in its adolescence. The atmosphere was filled with carbonic acid, out of which all this coal was made. The bright light of the sun, falling upon the green leaves which had absorbed this gas, gave them power to store up the carbon in their tissues. That carbon is this coal. And the sun-power

which formed it is still stored up in it, as heat. Is not the sun's force the agent which moves the steamship?

One step farther. Out upon the broad ocean floats the wealth and pride of many nations. The swift winged clipper and the cumbrous frigate; the New York yacht and the Dutch galliot alike spread their sails to the breezes of Heaven and are propelled over the waves. These birds of the sea, fostered by the science of navigation, have equalled the steamer in the accuracy of their flight. As the noble ship spreads sail after sail to the breeze, which wafts her away until she appears like a white cloud upon the sea, you involuntarily pause to consider whence the force which urges her on. Do you say it is the action of the wind upon her sails? But what causes the wind? Is it not the sun heating unequally the earth's surface causing the air to rise, and cooler currents, as wind, to rush in to fill the space?

But neither the independent steamship nor the wind-urged clipper have, in themselves, any means of certainty in their course. Formerly navigators were obliged to sail along the shore. If they missed sight of it they were lost. The narrow, contracted Mediterranean was too large for them. Now the mariner pushes fearlessly out into the boundless ocean, and crosses it as accurately as if he were following a beaten path. Stand by the side of him who guides that ship. By what rule does he turn her helm this way or that? In the little box you see in front of him is delicately balanced a bar of steel, which points out the North with undeviating accuracy. Guided by this he need never go astray. But what is the force which keeps this tiny thing true to the pole? The earth's magnetism. How is this produced? According to present science, by electric currents which circulate round the earth parallel to the magnetic equator. And the cause of these currents? The heat of the sun!

Do you say, This is very well, so far. But there is one force which is independent of the sun. My own right arm owes none of its might to the orb of day. But let us see. How is your body maintained in its integrity ? From what source comes the muscular fibre which contracts to produce the force ? Is it not from your food ? But this fibre wastes in doing work. An ordinary day's labor, continued for eighty days without supply, would destroy all the muscles by oxidation. But it is in this oxidation that force is produced. And the food which supplies this waste, this force, was, if vegetable, formed from the air by the action of sunlight. If your food was animal, the cause is only a step farther back. For the animal derived his flesh from the vegetable on which he fed. " Not, therefore, in a poetical, but in a strictly mechanical sense, are we the children of the sun."

The greatest of England's engineers, George Stephenson, once asked Dr. Buckland, then Dean of Westminster, " Can you tell me what is the power that is driving that train ?" alluding to a railway train passing at the moment. The learned Dean answered, " I suppose it is one of your big engines." " But what drives the engine ?" " Oh, very likely a canny Newcastle driver." " What do you say to the light of the sun ?" " How can that be ?" asked Buckland. " It is nothing else," said Stephenson. " It is light bottled up in the earth for tens of thousands of years ; light, absorbed by plants and vegetables, being necessary for the condensation of carbon during the process of their growth, if it be not carbon in another form ; and now after being buried in the earth for long ages in fields of coal, that latent light is again brought forth and liberated, made to work,—as in that locomotive,—for great human purposes."

How vastly important then is our sun, as a reservoir of force to our system. Though emanating from it only as

light, we have, by the curious correlation now indicated, all the forces produced which are in action upon our earth. We are thus brought to consider our sun as a magazine of force. The amount of heat he radiates to the earth has been already stated. It would melt a crust of ice on the earth's surface 100 feet thick, annually. As the earth receives only 1-2,300,000,000 of the heat sent forth, it follows that a layer of ice surrounding the sun at the distance of our earth, and one hundred feet thick, would be annually melted. Transferring this heat to the sun's surface, we find that there *it would melt a layer of ice forty feet thick every minute, and one ten and a half miles thick annually.*[1] *It would boil per hour seven hundred thousand millions of cubic miles of ice cold water. It is equal per hour to that which would be generated by the combustion of a layer of coal ten feet thick, entirely surrounding the sun; and per year, to such a layer of coal, seventeen miles in thickness!*

If such is the enormous loss of the sun, the question must arise, how does the sun get its force? By what sort of action is this enormous temperature maintained? Shall we say by combustion? "Were the sun a solid block of coal, and were it allowed a sufficient supply of oxygen to enable it to burn at the rate necessary to produce the observed emission, it would be utterly consumed in five thousand years."

Shall we say that the sun is a cooling globe? "Assuming the specific heat of the sun to be the same as that of water,—the terrestrial substance which possesses the highest specific heat,—in five thousand years, the entire mass of the sun would cool down 15,000°.

The sun turns on his axis once in twenty-five days. Can it be friction of his periphery against anything in surrounding space which produces this high temperature? Though we can not conceive of any such "brake," yet as

[1] Pouillet, *Op. Cit.*, p. 716.

we have the data, "we can calculate the total amount of heat which the sun could generate by such friction. We know his mass, and his time of rotation; we know also the mechanical equivalent of heat. From these data we deduce that the entire force of rotation, if converted into heat, would cover more than one, but less than two centuries of emission." This theory is therefore untenable.

Another proposition is based on the nebular theory of M. Laplace. This theory supposes the entire solar system to have once been a nebulous mass, extending far beyond the orbit of Neptune, the outermost planet. The tenuity of this mass must have been extreme. Several cubic miles of it would weigh but a single grain. Molecular attraction produced condensation, accompanied by a loss of heat. The contraction toward the centre not being uniform, a rotary motion was assumed by the mass, which increased in velocity with the diminution in bulk. Finally as the condensation went on and the centrifugal exceeded the central force, an exterior equatorial ring was thrown off, which soon ruptured into a planet. Other planets were thus formed, and in their turn produced satellites, until at length the principal mass was condensed into the sun. Now Prof. Helmholtz has shown that the mechanical force equivalent to the mutual gravitation of the particles of such a nebulous mass, would be 454 times the mechanical force now in our system; 453-454 of this force have been already wasted as heat. The 1-454 which remains, however, would raise a mass of water equal to the sun and planets in weight, 28 millions of degrees Centigrade. The heat of the oxyhydrogen blowpipe, sufficient to fuse and vaporize even platinum, is but 2,000° C. If the mass of our entire system were pure coal, by the combustion of the whole of it, only the 3,500th part of the above enormous quantity would be generated. If this condensation is still going on, it may be calculated that if the

diameter of the sun were diminished only the ten-thousandth part of its present length, by this act a sufficient quantity of heat would be generated to cover the total emissions for 2,100 years. Such a small change it would be difficult to detect even by the finest astronomical observations.[1]

There is one other theory which, however bold it may at first sight appear, deserves our earnest attention. This is "the meteoric theory of the sun's heat." We know that the interplanetary space is far from empty. That besides planets, satellites and comets, there are innumerable smaller yet ponderable bodies, all circulating in orbits about the central sun. These bodies sometimes cross the outer limits of our atmosphere, and being ignited appear as meteors. Those who have watched the heavens on a clear night know how frequent are these "shooting stars." At certain times they appear in vast numbers. In Boston 240,000 were observed in nine hours. The whole annual number would be estimated by hundreds or thousands of millions, and yet how infinitesimally small a portion of those falling to the sun pass near the earth. Moreover, from observations made upon Encke's comet, and from other data, we know that space is filled with a resisting medium, though excessively tenuous. The effect of this upon the larger planets in lessening their distance from the sun, and consequently quickening their revolutions about it, though not appreciable, may yet be considerable in the case of the smaller bodies, which may be rapidly approaching the sun. We have already noticed the heat occasioned by the fall of bodies to the earth. In the place of the planet let us set the sun, with 300,000 times the earth's mass, and instead of a fall of a few feet let us take the cosmical elevations, and we then obtain a means of gene-

[1] Prof. Helmholtz, *Interaction of Natural Forces*, *Phil. Mag.*, IV Series, Vol. XI, pp. 506, 514.

rating heat which transcends all terrestrial power. If an asteroid falls directly to the sun we find that its velocity just before striking would be 390 miles per second; if it revolve around the sun close to his surface, 276 miles per second. In the former case the heat developed simply by the mechanical collision would be 9,000 times that produced by the combustion of an equal asteroid of solid coal. In the latter it would be equal to that produced by the combustion of 4,000 such asteroids. If all the planets were to fall into the sun, the heat thus produced would cover the total emission for 45,589 years. Here then we have an agency competent to restore his lost agency to the sun. Though the very quality of the solar rays enables us to infer that the temperature of their origin must be enormous, yet in the fall of asteroids we find the means of producing such a temperature. Of course this showering down of matter upon the sun must produce an augmentation of its size. "But the amount of this increase, which would be sufficient to cover the calorific emission for 4,000 years, could not be detected by our most delicate instruments. If the earth struck the sun it would utterly vanish from perception, but the heat developed by its shock would cover the expenditure of the sun for a century."

Such is the beautiful theory of Mayer, published in 1848, in his "Dynamîk des Himmels." Says Prof. Thompson, following out the same idea: "The source then from which solar heat is derived is undoubtedly meteoric. The principal source, perhaps the sole appreciable efficient source, is in bodies circulating around the sun, at present inside the earth's orbit, and probably seen by us in the sunlight, called the zodiacal light. The store of energy for future sunlight is at present partly dynamical, that of the motions of these bodies round the sun, and partly potential, that of their gravitation toward the sun. The latter is gradually being spent, half against the resisting

medium, and half in causing a continuous increase of the former. Each meteor thus goes on moving faster and faster, and getting nearer and nearer the centre, until some time very suddenly it gets so much entangled in the solar atmosphere as to begin to lose velocity. In a few seconds more it is at rest on the sun's surface, and the energy given up is vibrated across the district where it was gathered during so many ages, ultimately to penetrate, as light, the remotest regions of space." [1]

Thus starting from some of those simple facts of nature which seem hardly to merit attention, and following them back to their origin, we find them linked together in a chain reaching throughout the solar system. One end is in the sun; the other binds together planet and satellite in a common brotherhood. From that sun all get life. It is the universal parent. In the eloquent words of Mr. Tyndall: "As surely as the force which moves a clock's hands is derived from the arm which winds up the clock, so surely is all terrestrial power drawn from the sun. Leaving out of account the eruptions of volcanoes and the ebb and flow of the tides, every mechanical action on the earth's surface, every manifestation of power, organic and inorganic, vital and physical, is produced by the sun. His warmth keeps the sea liquid and the atmosphere a gas, and all the storms which agitate both are blown by the mechanical force of the sun. He lifts the rivers and the glaciers up to the mountains, and thus the cataract and the avalanche shoot with an energy derived immediately from him. Thunder and lightning are also his transmuted strength. Every fire that burns and every flame that glows dispenses light and heat which originally belonged to the sun. In these days, unhappily, the news of battle is familiar to us, but every shock and every charge is an application or misapplication of the mechan-

[1] Prof. Wm. Thompson, *Trans. Royal Soc.*, Edinburgh, 1854.

ical force of the sun. He blows the trumpet, he urges the projectile, he bursts the bomb; and remember this is not poetry, but rigid mechanical truth. He rears the whole vegetable world, and through it the animal; the lilies of the field are his workmanship, the verdure of the meadows, and the cattle upon a thousand hills. He forms the muscle, he urges the blood, he builds the brain. His fleetness is in the lion's foot, he springs in the panther, he soars in the eagle, he slides in the snake. He builds the forest and hews it down; the power which raised the tree and which wields the axe being one and the same. The clover sprouts and blossoms, and the scythe of the mower swings by the operations of the same force. The sun digs the ore from our mines, he rolls the iron, he rivets the plates, he boils the water, he draws the train. He not only grows the cotton, but he spins the fibre and weaves the web. There is not a hammer raised, a wheel turned, or a shuttle thrown, that is not raised, and turned and thrown by the sun. His energy is poured freely into space, but our world is a halting place where this energy is conditioned. Here the Proteus works his spells; the self same essence takes a million shapes and hues, and finally dissolves into its primitive and almost formless form. The sun comes to us as heat; he quits us as heat; and between his entrance and departure the multiform powers of our globe appear. They are all special forms of solar power — the moulds into which his strength is temporarily poured in passing from its source through infinitude. To nature nothing can be added; from nature nothing can be taken away: the sum of her energies is constant, and the utmost man can do in the pursuit of physical knowledge is to shift the constituents of the never varying total, and out of one of them to form another. The law of conservation rigidly excludes both creation and annihilation. Waves may change to ripples

and ripples to waves — magnitude may be substituted for number and number for magnitude — asteroids may aggregate to suns, suns may resolve themselves into floræ and faunæ, and floræ and faunæ melt into air—the flux of power is eternally the same. It rolls in music through the ages, and all terrestrial energy — the manifestations of life as well as the display of phenomena — are but the modulations of its rhythm."